Electric Airplane Research Program

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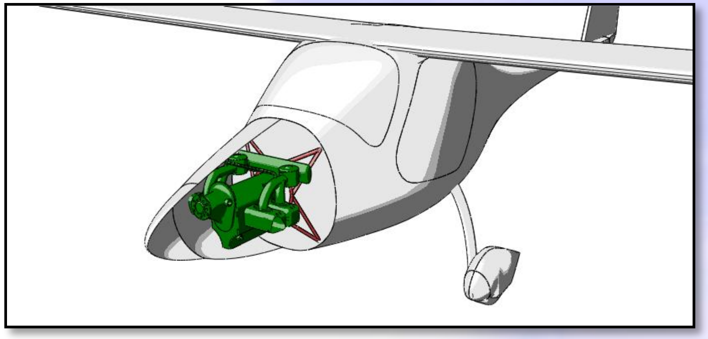
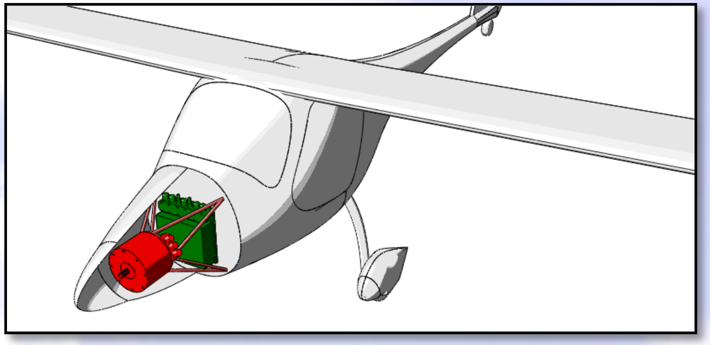
Program Overview

- Joint venture between NASA Ames, Stanford, & private industry
- Electric aircraft flight research program
  - Build & fly highly instrumented electric airplane testbed in Phase I
- Goals
  - Begin flight testing of electric testbed aircraft in October
  - Identify & investigate areas where scaling & other research is possible in Phase II
  - Establish applied research environment for Ph.D. research in green aviation





Initial Motivation

- "Green" aviation
  - Zero emissions
  - Dramatically less noise pollution (silent flight)
- Lower operational costs
  - Potentially lower life-cycle costs
  - ~1 cent/mile vs 15 cents/mile for ICE
  - Less maintenance
- Push electric drive train tech
  - Use strict constraints of aviation to apply "evolutionary" pressure to components
- Create fertile environment to engage/enthuse students with hands-on research opportunities

Electric Advantages for Sensing

- Quiet Operation
  - Near silent, powered flight possible
  - Allows sustained operation over urban centers
- Reduced Sensor Noise
  - Less mechanical vibration
  - Less electrical noise
- Low Thermal & Zero CO2 Emissions
  - Important for highly localized environmental data collection
  - 75% energy of ICE energy lost to heat vs ~5% for electric (15x less)

ElectraFlyer C arriving at Oshkosh '08

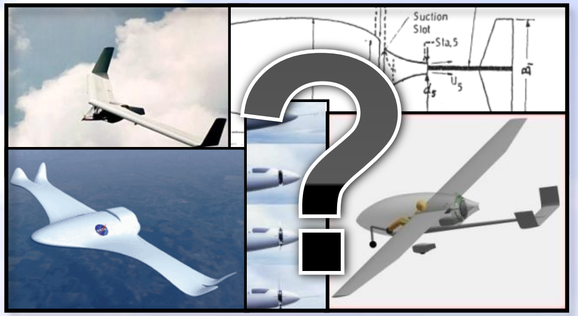
IR Image of internal combustion engine

Implementation

Project has 2 distinct phases:

- Phase I - 9 months
  - Build flying laboratory
    - 200km+
    - 45+ min on station
    - 100kts+
    - Payload: 340 lbs (2 people)
  - Identify EP pain points
  - Lay groundwork for Phase II

- Phase II – 2+ years
  - Research EP pain points
    - Especially tech scaling
  - Larger EP demonstrator
    - Range: 1000km ?
    - Speed: 120kts+ ?
    - Payload: 6+ people ?

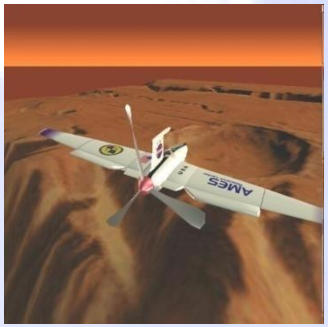


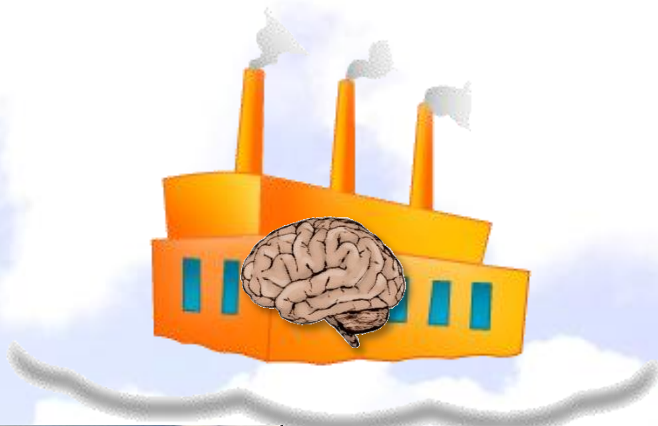
Team - Partnership

- Form a unique research partnership of 3 different types of research organizations:
  - Government: NASA Ames
  - Academia: Stanford University
  - Private Sector: etaTech & others

- Allows project to take advantage of benefits of all 3 to get task completed quickly and efficiently

Stanford/Ames "Idea Factory"





Education & Research Areas

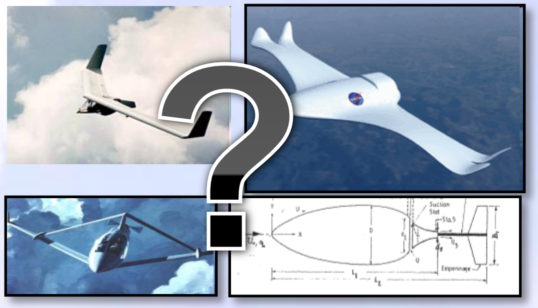
- Quiet Propellers
- Efficient Aero Structures
- Integrated vehicle/propulsion concepts
- Novel Configuration Concepts
- Vehicle Systems Integration
- Electric drive technologies
- Power Systems – Fuel cells, Battery management
- Electric aircraft thermal control

Incubator & test/validation environment for radical ideas - can be extended to large aircraft/other vehicles

Phase I to Phase II Transition

- What Phase I gives Phase II:
  - Foundational experience:
    - I&T, cert/flt procedures, FOM, HW
  - Understand viable (& pressing) areas of research
    - Reduction of flight test data
  - Can demo Phase II projects on Phase I testbed
  - Use the airframe as flying lab for other experiments not directly related to electric propulsion

- Phase II – 2+ years
  - Major research effort
  - Topics will be defined in part by Phase I results
  - Scaling likely to be major focus
  - Exact perf. goals TBD



Electric Airplane Testbed Configuration

Issue of Testbed Scale

- EP becoming feasible for small GA aircraft
- Societal impact of a green 2-seat airplane is small
- Real gains made with green regional commuter aircraft & 737s
- Decided to start small (GA size)
  - Develop technology scaling
  - Lower “buy-in” cost & schedule

VS

Testbed Hull Comparison

	Country	Payload (lb)	Dry Wt (lb)	GTOW (lb)	L/D max	KgKm/KJ	Range (nm) 75 kW-Hr
Antares 20 E	USA	441	1014	1169	56	2.15	799
Taurus	Slovenia	413	628	1042	40	1.61	637
Lambada	Czech	670	650	1320	30	1.55	379
Viva	Czech	398	644	1042	40	1.55	637
Sinus	Slovenia	609	626	1235	30	1.51	405
Stemme	Germany	419	1455	1874	50	1.14	445
Xenos	USA	570	750	1320	24	1.06	303
Whisper	South Africa	608	1102	1710	28	1.01	273
ElectraFlyer	USA	530	574	1103	20	0.98	302
Europa	UK	487	883	1370	27	0.98	329
Whisper	S Africa	551	1102	1654	28	0.95	282
Grob 109B	Germany	540	1334	1874	30	0.88	267
Taifun	Germany	503	1375	1878	28	0.76	249
Dimona	Austria	463	1237	1700	27	0.75	265
Breezer	Germany	616	704	1320	15	0.71	189
CTLS	Germany	620	700	1320	14	0.67	177
Sportrider	Italy	620	650	1270	13	0.65	171
J170	USA	680	640	1320	12	0.63	152
Sport Cruiser	Czech	562	758	1320	14	0.61	177
Sportster	Spain	462	858	1320	16	0.57	202
Parrot	Czech	530	790	1320	13	0.53	164
G3	Germany	650	670	1320	10	0.50	126
Sportstar	Czech	522	798	1320	12	0.48	152
Piper Warrior	USA	906	1534	2440	9	0.34	61
Cessna 172	USA	840	1718	2558	9	0.30	59

Antares 20E

L/D = 60
W_{pay} = 200 lbs

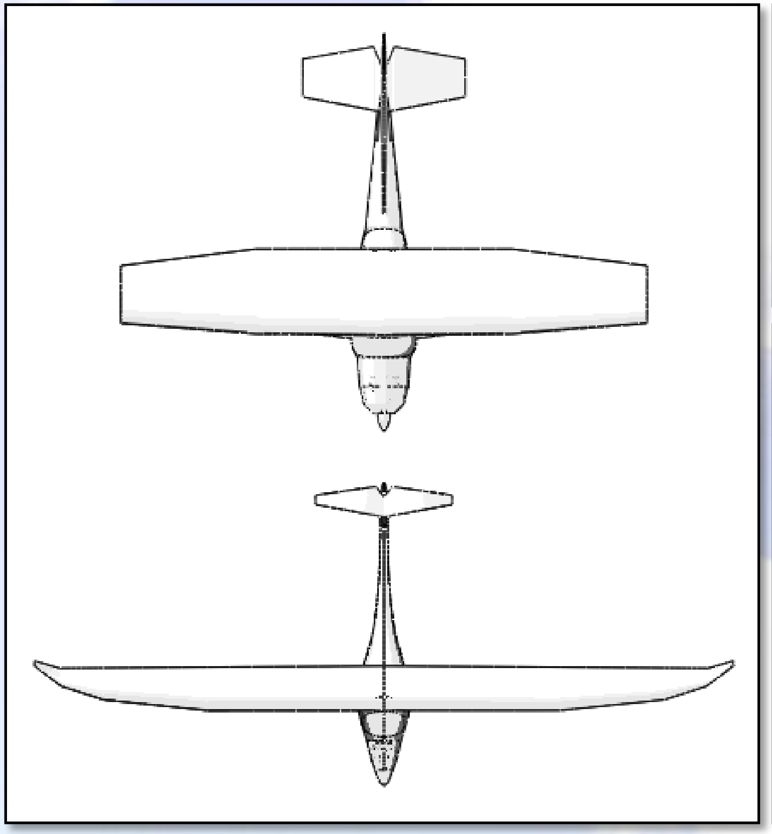
Pipistrel Sinus

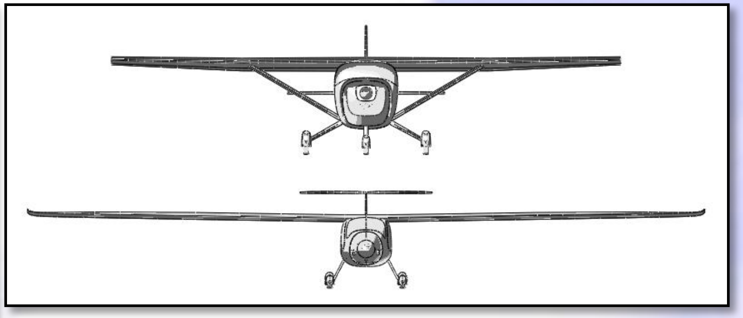
L/D = 30
W_{pay} = 800 lbs

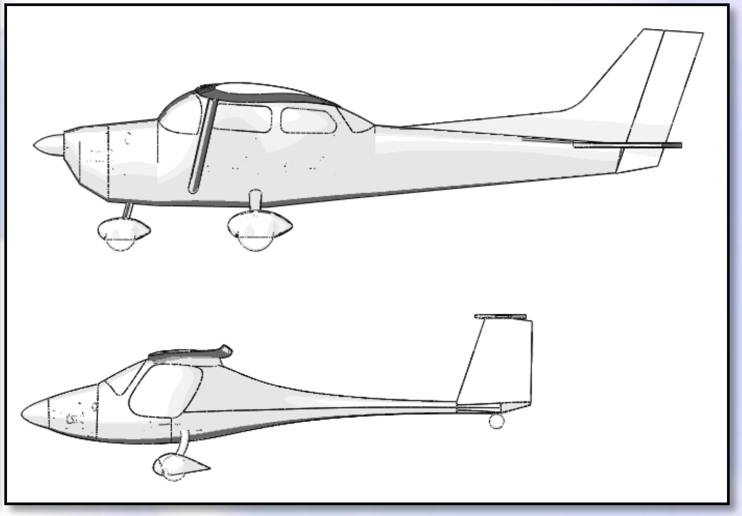
Cessna 172

L/D = 9
W_{pay} = 1300 lbs

C172 vs Pipistrel Geometry

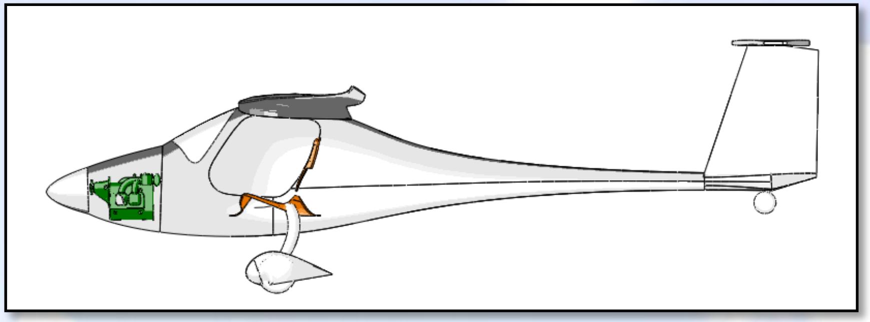




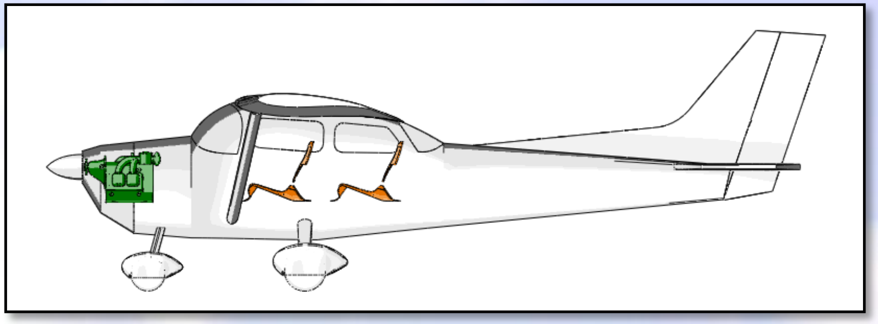


Cabin Useful Volume Comparison

- Pipistrel
  - 63.5 ft^3
  - - 4 ft^3 (Rotax 912)
  - - 19.5 ft^3 (people)
  - ~40 ft^3 for components



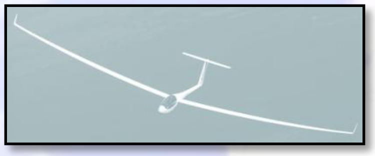
- Cessna
  - 142 ft^3
  - - 10 ft^3 (Lycoming IO-360)
  - - 39 ft^3 (people)
  - ~92 ft^3 for components



Weight & Payload Comparison

	Sinus	Cessna 172
	(lbs)	(lbs)
Empty	626	1717
Pilots	300	300
Fuel	101	318
Payload	293	223
Total	1320	2558
(Battery)	(394)	(541)

Motor-glider class selection



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Antares 20E

L/D = 30
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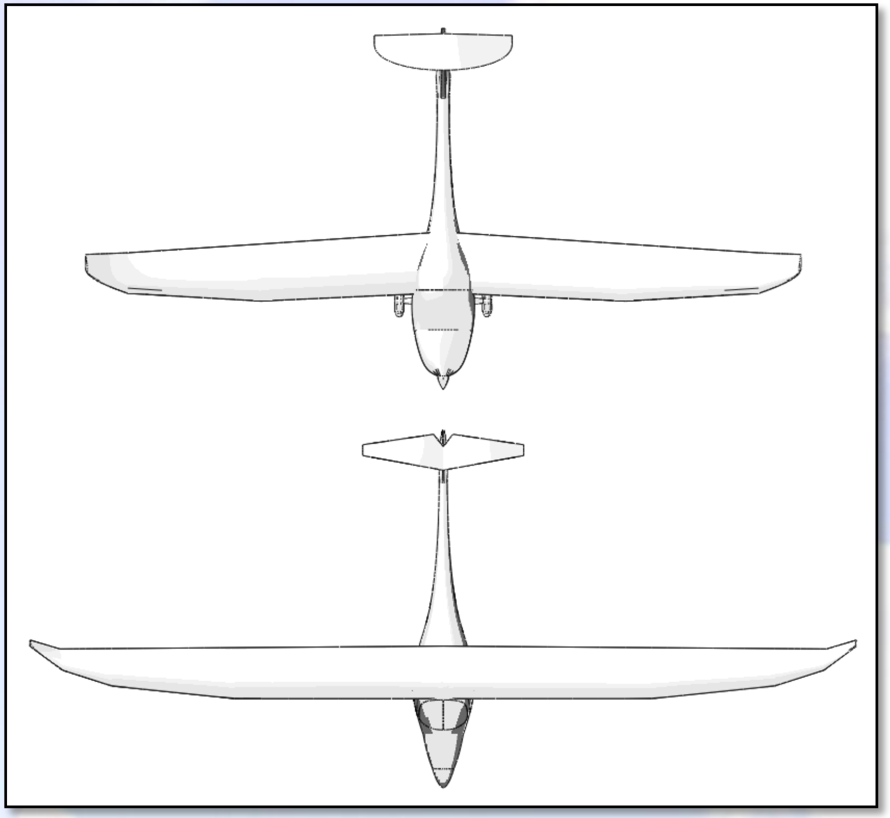
Pipistrel Sinus

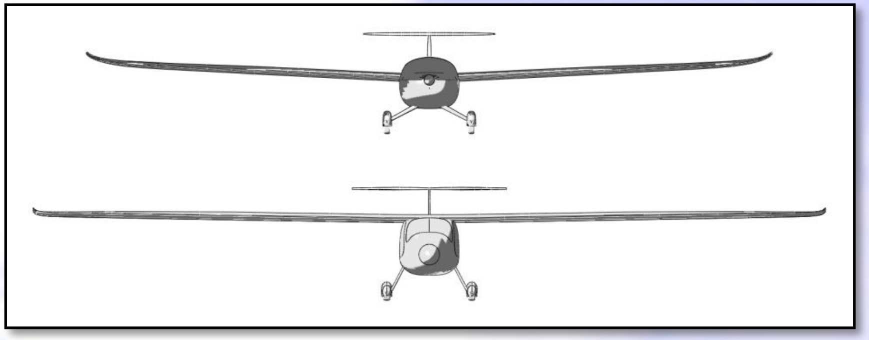
L/D = 9
W_{pay} = 1300 lbs

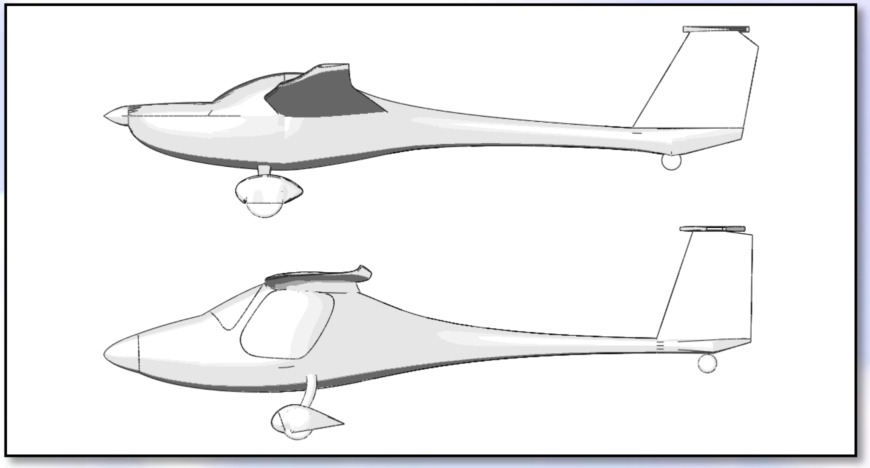
Cessna 172

- High L/D
  - Aero efficiency for range
- Cabin volume
  - Need space for components
- Mass
  - Lightweight aircraft better
- Regulatory
  - Less hassle better
  - Drives towards LSA class

Geometry Comparison







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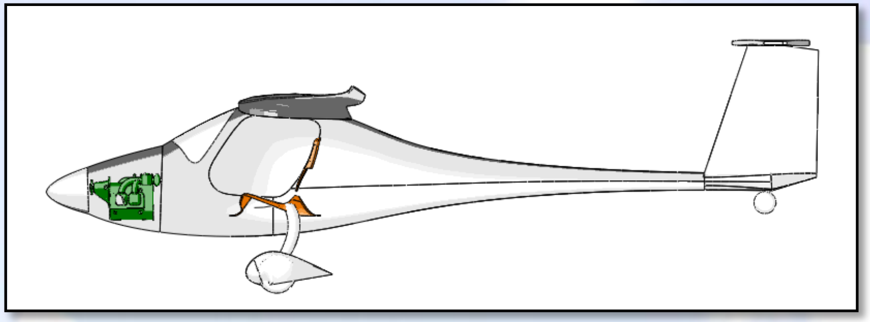
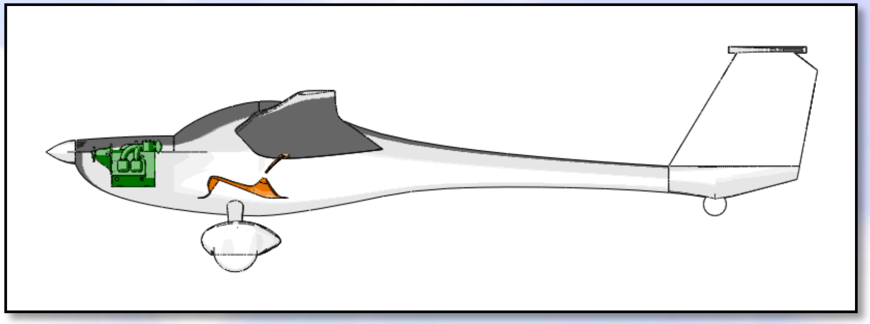
~40 ft^3 for components



- Lambada
  - 46.5 ft^3
  - - 4 ft^3 (Rotax 912)
  - - 19.5 ft^3 (people)

~20 ft^3 for components



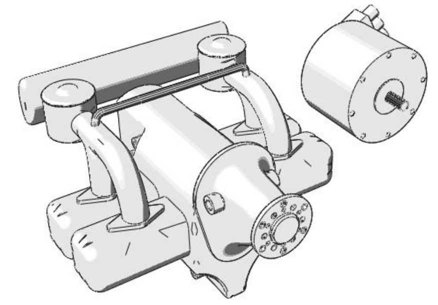
Batteries

Battery	Chemistry	Voltage (V)	Capacity (A-hr)	Weight (g)	Volume (mm^3)	Cells per Strand	Cont. Discharge (A)	# Strands	Pack Capacity (A-hr)	Runtime (hrs)
Sion Power	Li-S	2.1	2.5	15	22,385	143	1	103	257.5	1.03
Panasonic NCR18650	Li-Ion	3.6	2.9	45	17,716	84	--	58	168.2	0.67
Electrochem CB30	Li-Sulphuryl Chloride	3.9	7	52	24,912	77	0.14	55	385	1.54
Electrochem CB36	Li-Sulphuryl Chloride	3.9	30	213	98,189	77	0.14	13	390	1.56
Panasonic BR-C	Lithium PolyCarbon Monoflouride	3	5	42	26,546	100	1	52	260	1.04

- Many potential battery types – but not many work for manned aviation
- Energy storage method agnostic – chose batteries due to easier start
- Designing testbed to accept different batteries (fuel cells?) through lifetime
- Battery energy management expected to be major area of research

Motor/Controllers

Motor	AC/DC	Weight (Kg)	Nom. Power (kW)	Max Power (kW)	Max Torque (N-m)	Nom. Torque (Nm)	RPM at peak eta	Peak eta
Brusa HSM17.6.12	AC	53	40	82	223	85	3500	0.96
UQM 75kW	AC	41	45	75	240	180	3850	0.93
Apex Drive Labs DD31W	AC	38	31.3	46	576	158	750	0.9
CAPS	Supercon.							
Sumitomo	HTS	26		50	150			.97
Sumitomo	HTS	22		31	120			.97
American Supercon.	HTS							

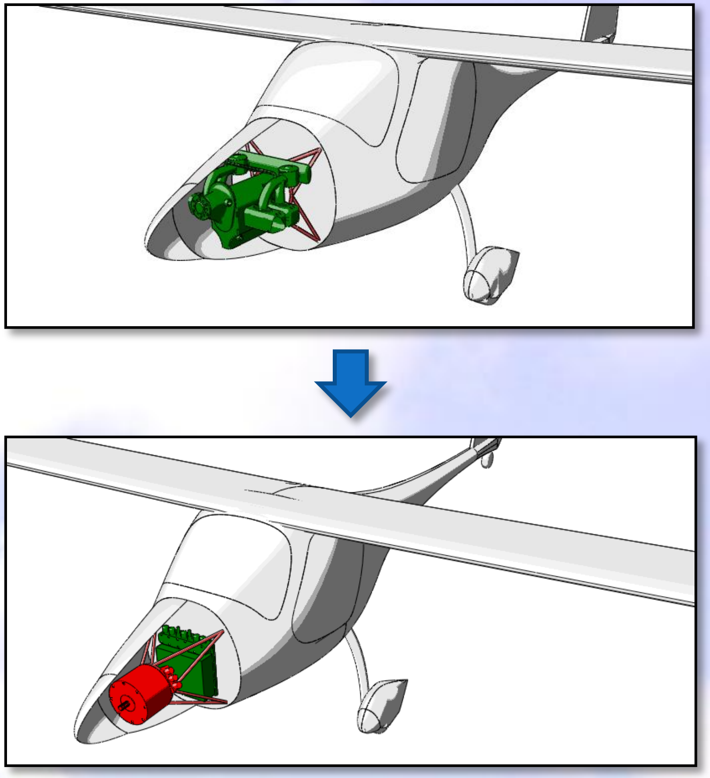


Rotax 912 ICE vs UQM 75 Electric Motor

- Base engine in Sinus is Rotax 912 (80 hp)
- Want same class of electric motor in testbed for apples to apples comparison

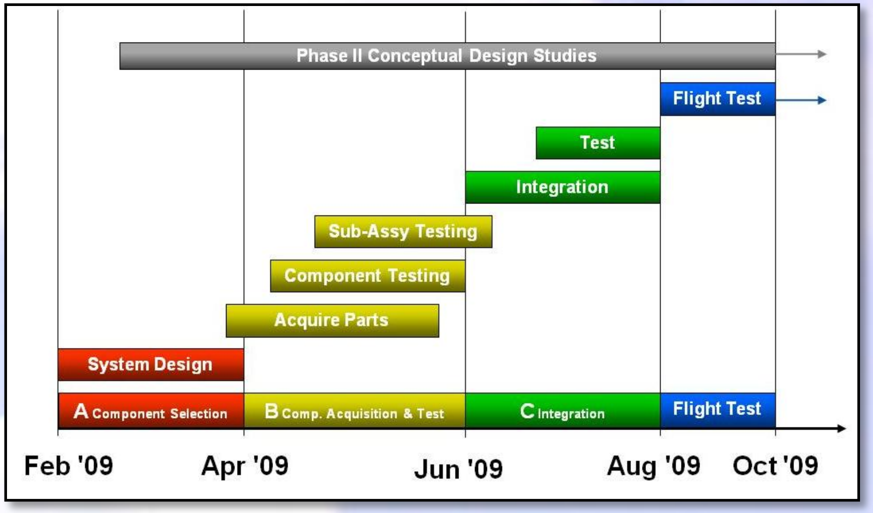
Component Selections

- Airframe
  - Pipistrel Sinus
- Battery
  - Panasonic Li-Ion as baseline, possibly Sion Li-S
- Motor/Controller
  - UQM 75 kW as baseline
- Have COTS primary component and then experimental alternative
- Expect ~300km range at 110 kts



Status/Current Work

- Final down-select & acquisition of components
- Definition of component & system level test plans
- Spec'ing flight instrumentation & data collection
  - Aircraft performance data
  - Electric system data
  - Cell-by-cell data
  - Thermal data



Questions?